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A number of feasibility measurements of the x-ray imaging properties of a capillary prototype optic for digital mammography were performed. The capillary prototype optic had input and output diameters of 4.15 mm and 7.5 mm, respectively. A mammographic scanning system was constructed to allow imaging of a larger field for some of the measurements. The optic showed good primary transmission (46%) at mammography energies. Images of a lucite contrast detail phantom, using a lead blocker, showed that the optic provides an increase in image contrast with a contrast improvement of 1.72 and a reduction of the scatter fraction to 0.018. The limiting resolution for the phosphor plate system (CR) was measured through the modulation transfer function (MTF). The 5% MTF for the stationary and scanned optic was 9 lp/mm and 8.4 lp/mm, respectively, compared with 5.4 lp/mm without the optics using a 0.3 mm focal spot and optimal magnification.

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Carolyn A McDonald 10/7/95

PI - Signature Date

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INTRODUCTION

The quality of conventional mammograms has been limited in 1) contrast by the large fraction of scattered photons and the low inherent contrast of the breast tissue, and 2) in resolution by geometric unsharpness determined by the finite x-ray focal spot size. Also, in digital mammographic applications detector resolution has been a significant limitation. Computed radiography (CR) photostimulable phosphor plates have lower spatial resolution than film and have been limited in their application in mammography where the detection and evaluation of microcalcifications requires very high spatial resolution. Attempts to increase the effective resolution of the CR plates using conventional magnification techniques would be limited to modest magnifications due to the increase in blurring associated with the focal spot.

X-ray capillary optics [1,2,3] small bundles of hollow capillary tubes, make use of the nearly total external reflection of x rays in a manner analogous to conventional fiber optics. These optics can be useful in addressing the problems above. X-ray capillary optics, due to their small angle of acceptance (critical angle = 1.6 milliradians for 20 keV photons), would reject at the entrance of the optic scattered photons which are at an angle greater than the critical angle. Focused arrays of these optics would be used between the breast and detector system to reduce scatter and enhance spatial resolution through magnification techniques.

At the onset of this postdoctoral fellowship, extensive measurements on the performance of individual capillaries and smaller non focused optics (at mammography energies) had been performed by Abreu et al.[4]. The fellowship allowed me to join the Medical Physics group at the University of Wisconsin at Madison where the imaging characteristics of capillary optics had begun to be investigated.

The purpose of the present work was to investigate the feasibility of using diverging glass capillary optics for digital mammography by modifying the scanning

gantry to permit measurements of the partial optics, performing measurements on the partial optic prototype in both static and scanned configurations and designing the final optics.

BODY

The mammographic scanning gantry was fabricated to allow the measurement of a partial capillary optic prototype built by X-Ray Optical Systems, Inc. (The scanning gantry allows the optic to be scanned in the horizontal plane while the phantom and detector shift in unison as shown in figure 1. The details of the scanner can be found in reference 5 which is a paper that our group submitted to Medical Physics.) The prototype optic is 16.7 cm long, and it tapers from an output diameter of 7.5 mm to an input diameter of 4.15 mm resulting in a magnification of 1.81. Though the prototype was not an optimal optic, it still was very useful in the performing of relevant imaging experiments.

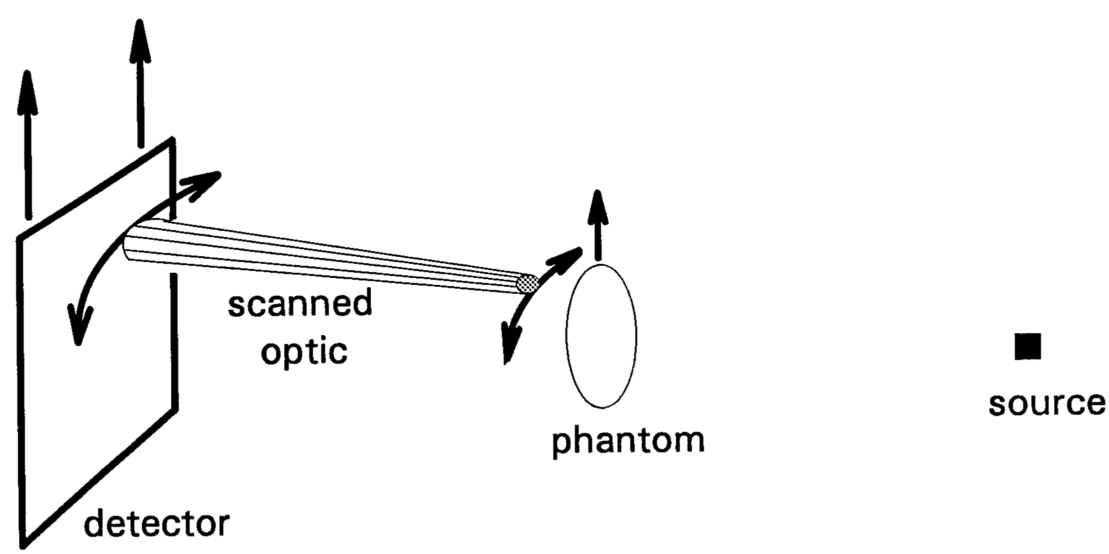

Figure 1. Scanning gantry geometry. The optic is scanned in the horizontal plane while the detector and phantom are moved in parallel vertical planes to allow imaging of the wide area object.

First, the primary transmission of the partial optics prototype was measured in a static configuration. The primary transmission was approximately 46%. Scatter fractions with and without the optic were measured using a 5 cm thick Lucite phantom, a field size of 16 cm and a lead beam blocker with a width of 3.1 mm as shown in figure 2. A rectilinear scan was done to obtain an image for the scatter fraction measurement with the optic. Measurements were also done with and without a 5:1 scatter reducing grid. The results for these measurements are summarized in Table 1.

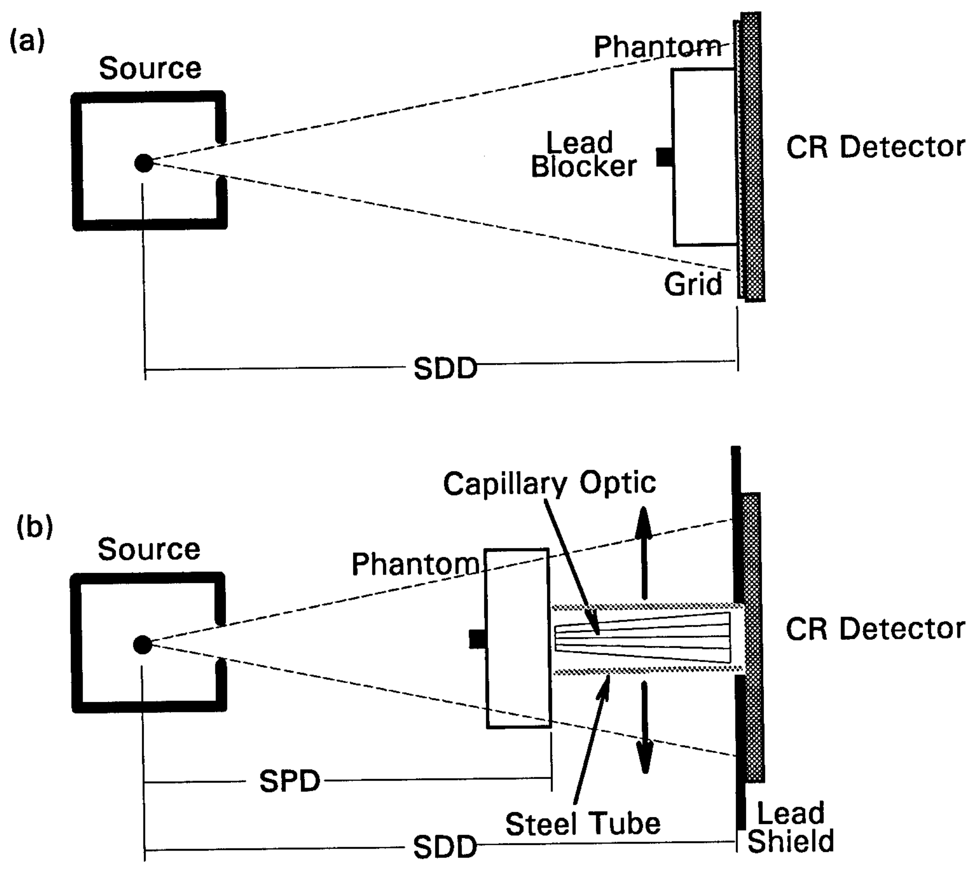

Figure 2. (a) Scatter fraction measurement geometry for normal acquisition with and without the grid. (b) The optic is scanned along with the lead shield. The shield is needed to keep scatter from bypassing the optic and being detected. The source to detector distance (SDD) = 42 cm and the source to phantom distance (SPD) = 24 cm.

Method	T_p	T_s	Scatter Fraction
Normal	˜ 1	˜1	0.450
5:1 Grid	0.660	0.200	0.170
Capillary Optic	0.460	0.003	0.018

Table 1. Scatter fractions and primary and scatter transmission factors of three methods of image acquisition.

From the scatter fractions in Table 1, a comparison was made of the capillary optic method to the normal method (no anti-scatter device used) to calculate the optic transmission necessary for equal SNR. That point was ≈ 50%. A comparison to the actual transmission of 46% shows that the optic gives the same SNR/dose as a 5:1 anti-scatter grid. Even though this optic is at the break even point compared to a grid, new manufacturing processes and greater linearity are expected to give higher primary x-ray transmissions. Any higher optic transmission will permit additional gains in SNR or a possible decrease in dose with its use.

The contrast improvement was also measured. This is important because it is directly related to reduced scatter. For these measurements a 5cm thick lucite contrast phantom containing holes of decreasing size in one direction and decreasing depth in another was used. To measure the contrast, the phantom was imaged, with grid and without a grid, using CR plates on a GE Senographe mammography unit set at 27 keV and 35 mAs. The phantom was then scanned using the capillary optics at 27 keV and 10 mAs. These images are shown in figure 3 and a quantitative contrast comparison of the cases with and without the grid are shown in figure 4.[5] The capillary optic showed better performance compared to the cases with and without a grid for all hole sizes. The 5:1 grid yielded, an average contrast improvement factor of 1.2 compared to no grid. For the capillary optic the factor was 1.7, showing that the optic does an excellent job of reducing scattered radiation.

(a)

(b)

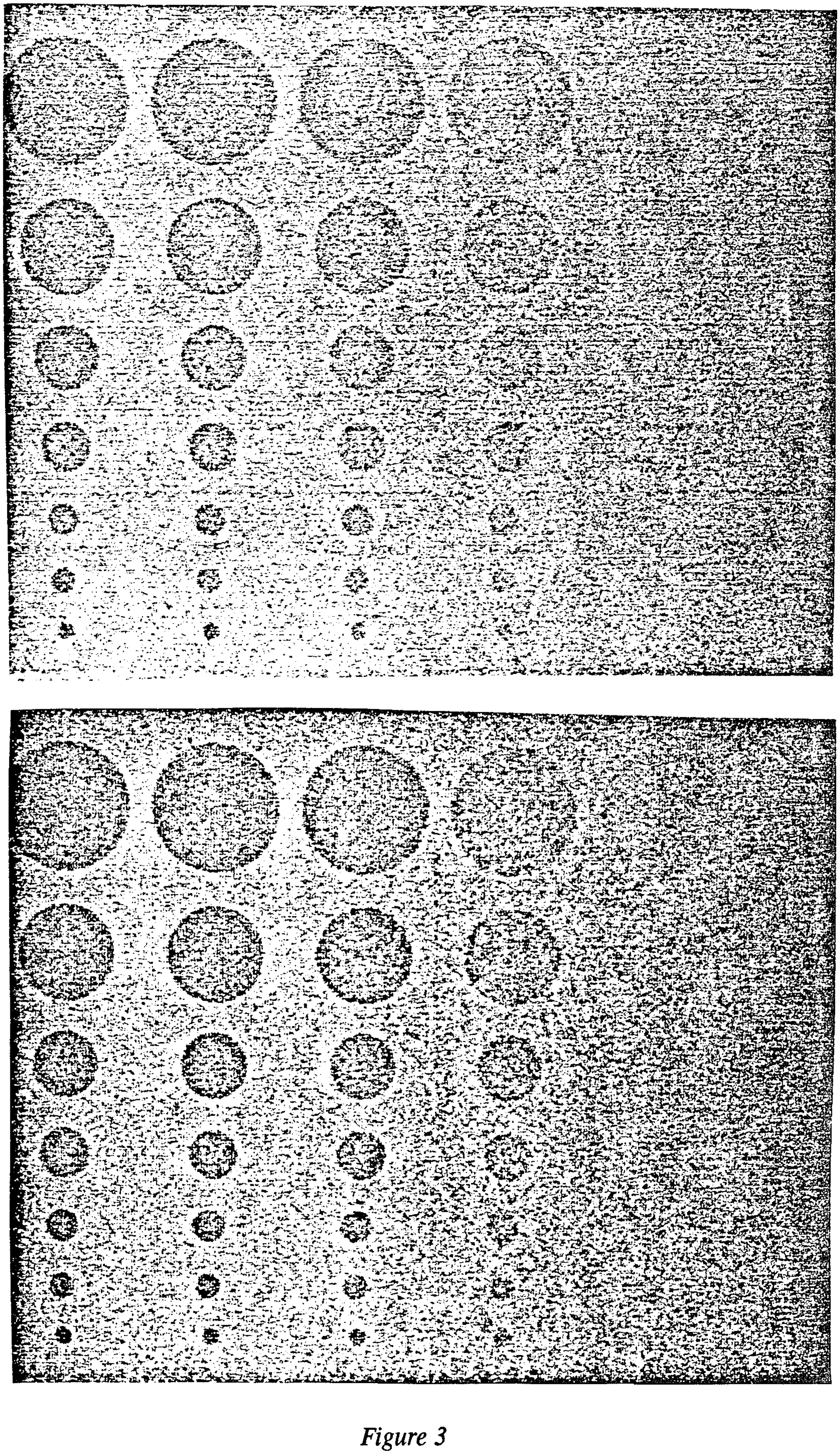

Figure 3

(c)

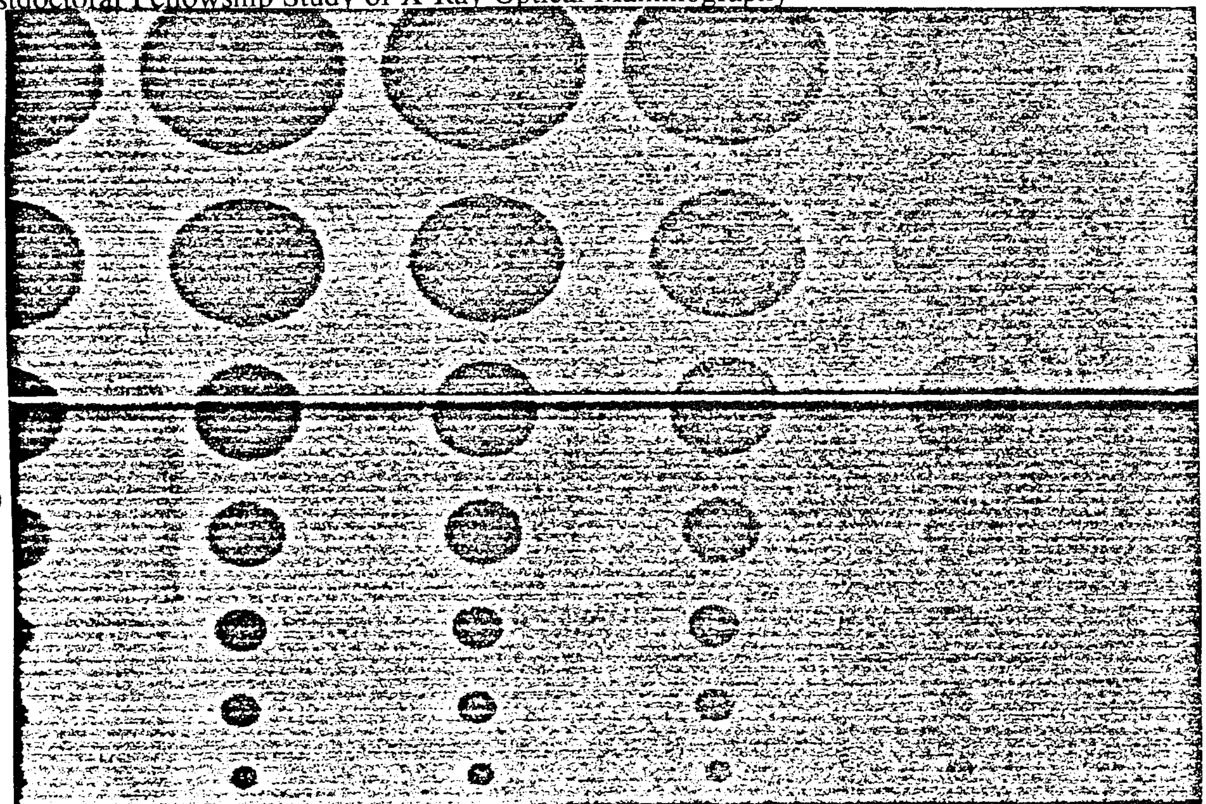

Figure 3. Images of contrast-detail phantom (a) without an anti-scatter grid, (b) with a 5:1 grid and (c) with the capillary optic.

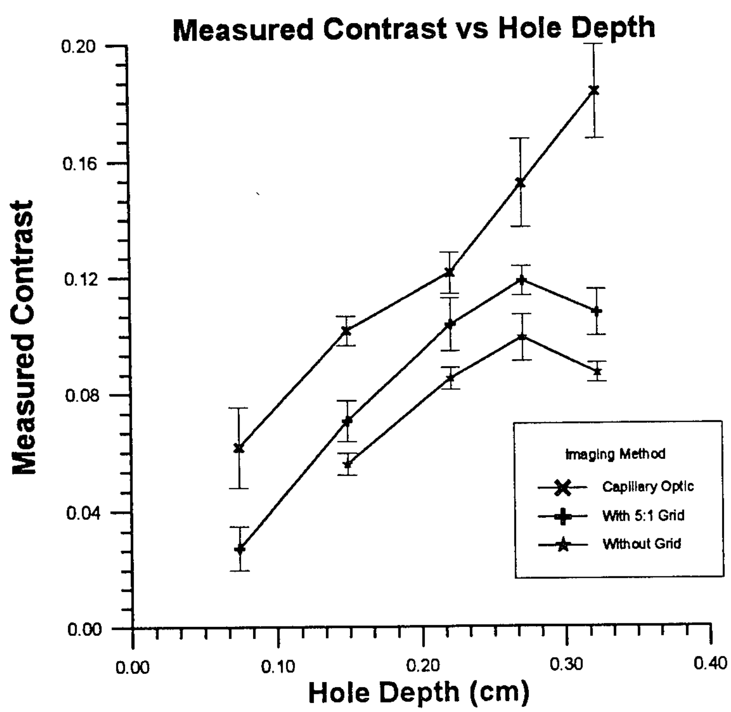

Figure 4: The average measured contrast of the contrast-detail phantom is plotted versus depth for the methods with the optic, with a 5:1 grid and without a grid.

To determine the limiting resolution for the phosphor plate system with and without the optics, modulation transfer function (MTF) measurements were performed. The MTF was measured using the edge response function of the phosphor plate imaging system (CR) with and without the optic. (For details of these experiments, see reference 5.) The MTF curves are shown in figure 5. The MTF limiting resolution point for this comparison was defined to be the spatial frequency at which the MTF curve drops to 5%. When optimal geometric magnification (and large focal spot = 0.3 mm) is used the limiting resolution increases to 5.4 lp/mm. Using the capillary optic in a stationary mode (with a large focal spot = 0.3 mm), the 5% MTF level is increased to 9 lp/mm. With the scanned optic mode the limiting resolution decreased to 8 lp/mm. The scanned MTF is reduced because the scanning produces the possibility of blurring due to a non-linear taper of the optic or mere vibration of the scanning system. The performance of the scanned optic could be improved by having an optic with a more linear taper or by eliminating the vibration of the scanning system with the use of a more elaborate system.

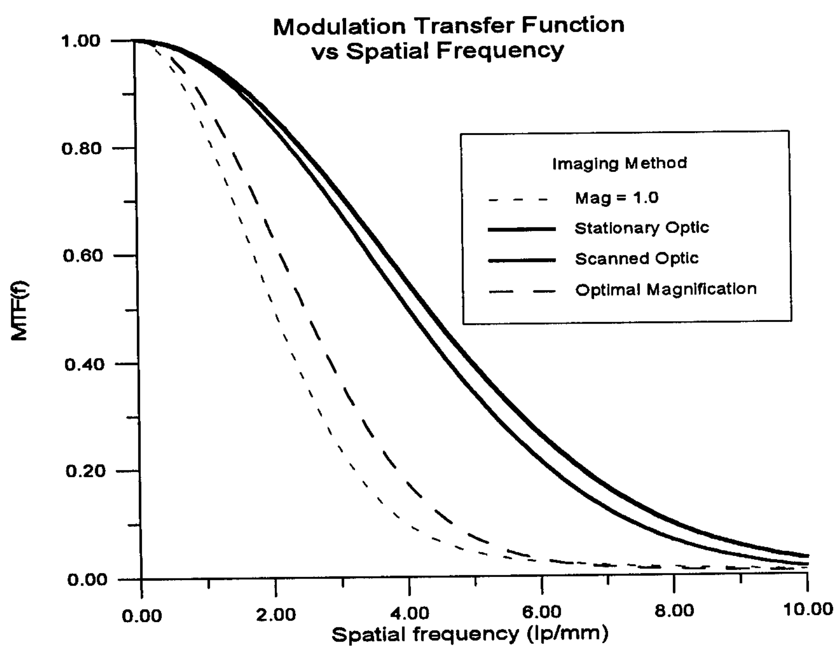

Figure 5. MTFs of four CR imaging methods.

Currently, images of a Radiation Measurements, Inc. (RMI) Mammography Accreditation Phantom, Model 156, are being obtained with the scanning gantry and optic. Imaging a mammographic phantom that is used clinically with the optic is an important next step because it will allow us to subjectively evaluate the performance of the optic in phosphor plate mammography compared to conventional screen/film mammography, magnified screen/film mammography without the optics and magnified screen/film mammography with the optics. The RMI phantom contains objects which simulate micro-calcifications, fibrous structures in ducts, and tumor-like masses[6]. (A schematic of the RMI phantom is included in the appendix.) This phantom is used by mammography quality assurance groups as an integral test in determining the ability of the mammographic unit to image structures similar to those found clinically. Images of the phantom have been obtained in the normal fashion on film and on the CR plates with no optic. The screen/film combination does better, as expected, since the CR plates (without the optic) have a resolution limit of 5 lp/mm as opposed to the ~ 15 lp/mm resolution limit of the film. Since the optic has a small output diameter and the RMI phantom contains objects in a 8 cm x 8 cm region, the mammography unit was modified to allow it to run continuously so that the optic had enough time to scan the phantom. We are just starting to scan the phantom with the optic so there are no images available at this time.

CONCLUSIONS

Capillary optics showed nearly total rejection of scatter. This reduction in scattered radiation causes an improvement in image contrast by an average of 70% over methods with no anti-scatter device and 40% over methods using the 5:1 grid. The optic transmission was 46%, which is very promising since good total transmission is required to give a reasonable total breast dose. With the use of the optic (magnification

= 1.81), the limiting resolution of the CR system was increased to 9 lp/mm from 5 lp/mm without the optic. The resolution increase is linearly dependent on the magnification factor of the optic. If an optic with a magnification of 3 was obtained, then the limiting resolution could be increased to 15 lp/mm. New optics with larger magnifications should facilitate the use of phosphor plates as digital detectors capable of imaging the entire breast. Digital mammography would have all of the advantages of digital processing, such as image processing, image transmission and storage, and computer aided diagnosis.

The test optic was not large enough to be clinically feasible. However, because the measurements done on the optic showed excellent agreement with theoretical predictions, improvements in the manufacturing technology of the optics should produce imaging improvements as well.

Specific plans for next year:

After the images of the RMI phantom are obtained with the optic, noise power spectra measurements for the optic and the PCR plates will be set-up in the lab. We will investigate noise properties of the magnified phosphor plate images compared with conventional mammography.

In the next couple of months, we expect to receive (from X-Ray Optical Systems) an optic with a larger output diameter (up to 2 cm) and a more uniform linear taper. Once this optic is in hand, transmission, scatter, contrast and MTF measurements will be repeated to determine the overall imaging capabilities of the new optic. Hopefully, we can then image excised specimens and the RMI phantom with the new optic using the same modalities.

The scanner is also being redesigned so that only the optic/source will be scanned and the detector and object will remain motionless.

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[6] User Manual - Mammographic Accreditation Phantom, Model 156, RMI Radiation Measurements, Inc., Middleton, Wisconsin.

APPENDIX

1) Schematic of RMI phantom

	Region Materials
1.	1.56 mm nylon fiber
2.	1.12 mm nylon fiber
3.	0.89 mm nylon fiber
4.	0.75 mm nylon fiber
5.	0.54 mm nylon fiber
6.	0.40 mm nylon fiber
7.	0.54 mm simulated micro-calcification
8.	0.40 mm simulated micro-calcification
9.	0.32 mm simulated micro-calcification
10.	0.24 mm simulated micro-calcification
11.	0.16 mm simulated micro-calcification
12.	2.00 mm tumor-like mass
13.	1.00 mm tumor-like mass
14.	0.75 mm tumor-like mass
15.	0.50 mm tumor-like mass
16.	0.25 mm tumor-like mass